STRATEGY
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PROJECT

NEW MADRID SEISMIC ZONE

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ABSTRACT

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The New Madrid Seismic Zone is one of the most potentially dangerous natural hazards that exists anywhere in the continental United States. Having produced three of the greatest earthquakes known to man over a 60-day period during the winter of 1811-1812, its destructive potential is real. Though general knowledge of this seismic zone is increasing, it is still not well founded. The possibility of a near term major earthquake holds serious implications for the nation. When it occurs, it will have a significant impact upon the military. This paper reviews the history of the New Madrid Seismic Zone, explains likely effects of a major earthquake and the anticipated levels of damage and disruption that would result, and covers the latest available scientific analysis for the likelihood of a recurrence of a major event. Finally, the paper reviews the current status of DOD planning for the response and recovery roles of various military organizations.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

NEW MADRID SEISMIC ZONE

The New Madrid Seismic Zone in the central United States is one of the most active seismic zones in the world, with hundreds of earthquakes annually. If a major earthquake were to occur in this zone, it would have a devastating effect upon the nation. Requirements for emergency response and for a long and difficult recovery would severely tax the resources of the entire country.

This paper reviews the history of the New Madrid Seismic Zone, explains likely effects of a major earthquake, describes expected levels of damage and disruption, reviews evidence of the likelihood of a major earthquake, and describes the current status of planning within the Department of Defense for its expected response and recovery missions.

The need to understand the New Madrid Seismic Zone

During the winter of 1811-1812, the North American continent was severely shaken by a series of earthquakes. The overall period of geological turmoil actually lasted several months, but it included a 60-day span during which there were at least three great earthquakes and hundreds of aftershocks. Many of the aftershocks were major earthquakes themselves.

The central Mississippi Valley region was still relatively unexplored and very sparsely populated in those early days of the nineteenth century. The town of New Madrid, located on the west bank of the Mississippi River in what is now the bootheel region

of southeast Missouri, was the largest settlement in the area at that time. Situated almost directly above the epicenter of one of the three great earthquakes, the town and the surrounding area were almost totally devastated. Thus, this region has come to be known geologically as the New Madrid Seismic Zone (NMSZ).[1]

On a modern map of the United States, the New Madrid Seismic Zone consists of a large region of the central United States around the Mississippi Valley. It includes southern Illinois, southeastern Indiana near the Ohio River, western Kentucky,

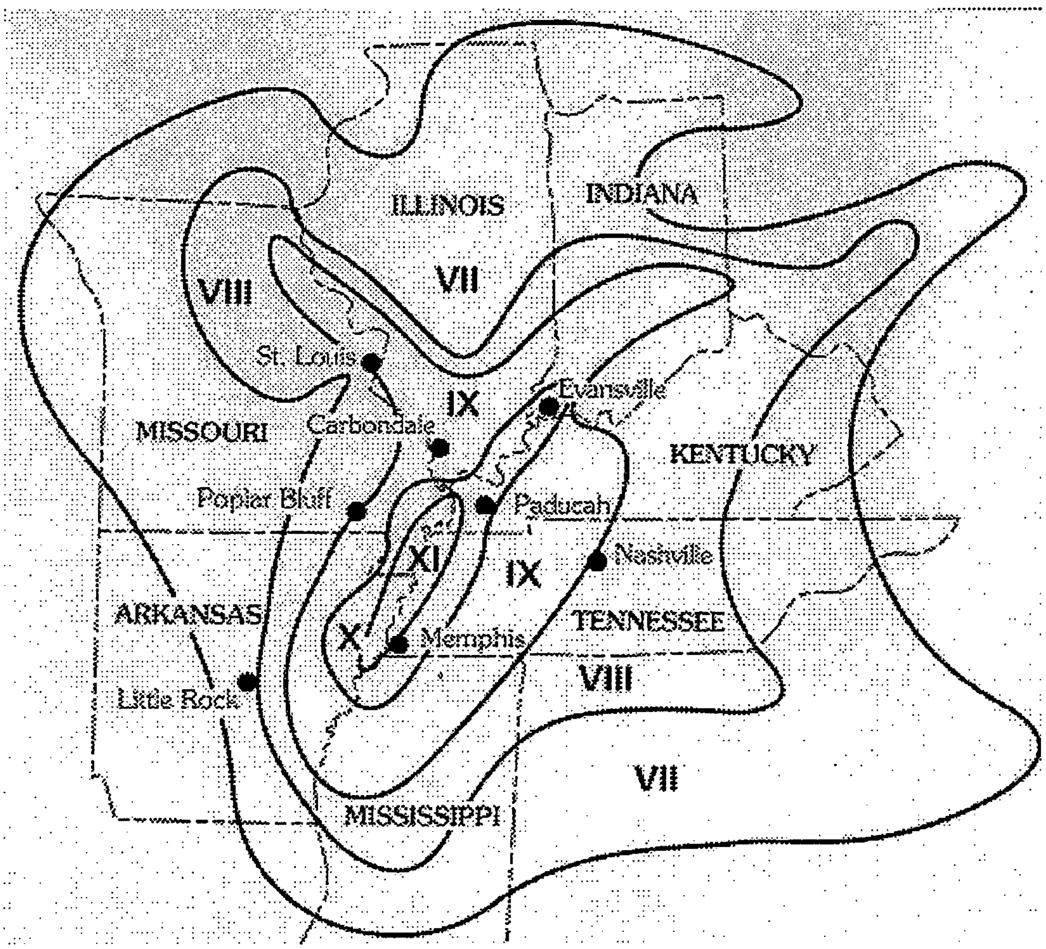

Figure 1 - New Madrid Seismic Zone[2]
Sketch of NMSZ with predicted Modified Mercalli Intensity zones.

southeastern Missouri, central and eastern Arkansas, west Tennessee, and northwest Mississippi.[3] (See Figure 1.)

Because the area was so sparsely populated during the winter of 1811-1812, the true impact of the earthquakes was not fully appreciated outside the region at that time. Stories of the devastation became stuff of legend as the years went by. It was not until 1912, almost a full century after the event, that the U.S. Geological Survey (USGS) completed the first official report on the earthquakes.[4] Still decades later, following the Loma Prieta (California) Earthquake of October 1989, the United States Congress became concerned about the hazards and risks of earthquakes and directed the USGS to begin an intensified study of the New Madrid Seismic Zone.[5]

Today, the great earthquakes of 1811-1812 are recognized as some of the largest to have ever occurred in the world. They are certainly the largest earthquakes to have occurred east of the Rocky Mountains in historic times.[6] Within the United States, only the Great Alaskan Earthquake of 1964 was larger.

Since the New Madrid Seismic Zone is an active earthquake region today, it is only a matter of time before the United States experiences a major earthquake in its heartland. There is no way that the forces of nature can be restrained. Therefore, it is incumbent upon the country to prepare itself for such an eventuality. Measures in mitigation and preparations for response and recovery must be aggressively pursued. The

individual states and the Federal Government share this responsibility . Department of Defense agencies are involved at both levels as the state governors direct their National Guard forces, and as the Federal Emergency Management Agency directs other DOD forces.

Plate tectonics of the New Madrid Earthquake Zone

The presence of the NMSZ in the central United States is not well known among the general public. It is much more common to think of the Pacific coast region when considering earthquakes in the United States. Obviously, this is due to the more frequent earthquake activity in California. It is helpful to understand the nature of the NMSZ and why it differs from the Pacific coast seismic zone.

The earth's surface is made up of a series of rigid plates. Plate tectonics is the scientific explanation for the creation and movement of these plates. The North American Plate is created by rising molten material in the mid-Atlantic region and extends to the Pacific coast of the continent. There it meets the Pacific Basin Plate. These two plates tend to move in a parallel fashion with the Pacific Basin Plate moving in a northward direction relative to the continental plate. The boundary between the plates can be seen clearly on the earth's surface. The San Andreas Fault in California is part of this plate boundary. As the two plates experience differential

movement, they produce the earthquakes for which the region is so well known. These earthquakes occur on or near the surface, where the earth's crust is composed of stable igneous and metamorphic rock.[7]

In contrast, the NMSZ is an intraplate seismic zone. Much less is known about the behavior of this type of seismic zone because their faults tend to lie deeper within the plate itself. Scientific study of these faults is relatively new. Also, since these faults release their energy much less frequently, there have been fewer opportunities to observe and study their behavior.

In prehistoric times, the mouth of the Mississippi River was located nearer its modern-day confluence with the Ohio River. Over the centuries, the alluvial deposits of Ice Age and the Appalachian Mountain Range eroded and the Mississippi Embayment was created. This embayment is the accumulated unconsolidated sediments that have filled the Mississippi River valley. Over time this process caused the mouth of the river to migrate southward from its original site to its modern location on the Gulf of Mexico. The continuation of this process can be observed today as the Mississippi River delta extends out into the Gulf. The embayment overlying the continental plate in the NMSZ is approximately one kilometer thick.[8]

Unlike the San Andreas Fault, the earthquake faults of the NMSZ are located deep within the rigid rock formations of the

continental plate. Scientists have estimated that the location of the faults within the plate may be as deep as five to fifteen kilometers.[9]

Earthquake magnitude and intensity

In describing earthquakes, it is important to understand the difference between the terms "magnitude" and "intensity."

Magnitude expresses the total amount of energy released by an earthquake and is determined by measuring the amplitude of surface waves produced. Thus, it is a measure of absolute size and strength and is not site specific. The Richter Scale, named for its developer in 1935, is an open-ended logarithmic measure using standardized recording instruments to measure the amplitude of surface waves. Since it is logarithmic, an earthquake with a Richter magnitude of 7.0 is ten times stronger than one of magnitude 6.0. Earthquakes of Richter magnitude greater than 8.0 are referred to as "great" earthquakes. Those of magnitude 7.0-8.0 are called "major" earthquakes.

Intensity is an indication of an earthquake's severity at a specific location as determined by type of damage observed. The Modified Mercalli Intensity Scale which grades effects into twelve classes is accepted for use in the United States. A description of the twelve classes of effects of the Modified Mercalli Intensity Scale is given in Table I.[10]

Earthquake magnitude and intensity are interrelated. The energy of an earthquake (magnitude) acting upon the local geology and overlying soil and water bodies results in damage (intensity). Figure 1 shows the expected intensities in the central United States due to a major (Richter magnitude 7.6) earthquake in the NMSZ. The historical eyewitness accounts of the great earthquakes of 1811-12 gave damage descriptions that would have been Class XI or XII on the Modified Mercalli Intensity Scale.

Earthquake effects

As discussed above, the tectonic characteristics of the NMSZ differ significantly from those of the Pacific coast seismic zone. Therefore, different earthquake effects are experienced within the two zones.

The surface faults of the Pacific coast seismic zone release their stored energy much more frequently, resulting generally in smaller earthquakes in terms of Richter magnitude. These surface wave effects are more quickly attenuated in the solid rock formations which make up the earth's surface. Thus, the resulting intensity of these earthquakes tends to be highly localized.

In contrast, the NMSZ is an intraplate zone. It is capable of storing much more energy with the potential to produce great earthquakes, such as those of the winter of 1811-1812. As a deep

intraplate seismic zone, the surface waves can be transmitted much further, with the effects of a significant earthquake here being felt over a much greater area.[11] The earth's crust in the NMSZ attenuates seismic energy only about 25 percent as effectively as the crust in the western United States. Therefore, damaging seismic wave amplitudes will travel much farther beyond the central United States. Especially noteworthy is the fact that local geomorphic conditions will magnify these amplitudes almost ten-fold in the Memphis, Tennessee and the St. Louis, Missouri areas.[12] The different soil conditions and overall lack of adequate seismic design of structures in the Mississippi Valley region would result in much more extensive and widespread damage in a New Madrid earthquake than would be expected from an event of similar Richter magnitude in California.[13]

There are several different specific effects of earthquakes which could produce damage. Primary effects are ground shaking and displacement, uplift and subsidence of geologic formations, and liquefaction of soils. Most other noted effects, such as flooding, are second or third order effects.

The very name "earthquake" is derived from the effects of ground shaking and displacement. These are the result of several different types of surface waves produced during an earthquake. These surface waves may cause the earth surface to displace vertically, horizontally, or in combinations which create a

literal wave effect. The more flexible a structure is, the better it can withstand this effect. Unfortunately, many man-made structures are not designed to survive strong ground shaking.

During a great major earthquake, especially in the intraplate regions, large subsurface geological formations of rock sometimes can displace within the overlying unconsolidated sediments. Uplift or subsidence of the earth's surface can result from the relative movement of these masses. While these changes in surface elevation can be relatively minor, the resulting effects can be dramatic.

Ground shaking can cause the subsurface soils to liquefy, or become "quick," in areas such as river valleys, where the subsurface regions are saturated with ground water. When this happens, a wide spectrum of spectacular and bizarre events may result. In some cases, large spouts of liquefied sands may spew up from below ground causing changes in local elevation and topography. It can also cause massive land and mud slides on slopes and river banks as the underlying strata liquefies. Great damage can occur if the ground beneath a building temporarily liquefies, losing its capacity to hold the weight of the structure above and allowing differential settlement or collapse.[14]

The history of New Madrid Earthquakes

Studying the history of earthquakes in the NMSZ is useful in trying to predict the effects of future earthquakes. Unfortunately, since significant New Madrid earthquakes are relatively infrequent, the records are limited.

Much of what is known about the great earthquakes of the winter of 1811-1812 has been passed down in eyewitness accounts. The geological study of the area has been able to interpret those accounts and provide a scientific explanation for many of the physical effects that were described.

The three great earthquakes of 1811-12 are among the largest known in the world. Their estimated Richter magnitudes were 8.1 (16 Dec), 7.8 (23 Jan), and 8.0 (7 Feb).[15] Within the United States itself, only the great Alaska earthquake of 1964, measuring 8.4, is known to have been of greater magnitude than these. The immediate succession of three great earthquakes, occurring over a 60-day period, was a phenomenal geological event. The total period of activity included hundreds of aftershocks, many with Richter magnitudes estimated to be between 6.5 and 7.6.[16]

In terms of area affected, they may be the strongest historical shocks in the world. The area of almost total destruction was 50,000 square miles,[17] and the earthquakes were felt over an area of at least one million square miles.[18] Church bells rang in Richmond, Virginia, and people felt the ground move

as far away as New York City and Montreal, Canada.[19] More than 1800 aftershocks large enough to be recorded as far away as Louisville, Kentucky occurred in the first five months following the first great earthquake. Noticeable aftershocks continued in the NMSZ until at least 1817.[20]

Scottish naturalist, John Bradbury, was a passenger in a large boat moored to a small island in the Mississippi River near the Chickasaw Bluffs during the earthquake. According to his account, the river became extremely turbulent and soon there was a roar as the vertical banks began plunging into the river creating swells that threatened to capsize the boat. The river channel became so obstructed by fallen trees and other debris that it was unnavigable.[21]

In fact, massive landslides were common along the Mississippi River bluffs from Cairo, Illinois, to south of Memphis, Tennessee. River banks hundreds of miles away from the epicenters collapsed.[22] These were caused by a combination of liquefaction and ground shaking.

Evidence of uplifting and subsidence was noted in several accounts. The landscape throughout the region was changed as the bottoms of streams, lakes, and ponds were thrust up causing their waters to run off and inundate other lands. The town of New Madrid subsided from an elevation of about 25 feet above the Mississippi River to only 10 feet.[23]

Probably the most dramatic instance of uplifting was accounts of two short-lived rapids which developed on the Mississippi River in the vicinity of New Madrid immediately following the 7 February earthquake.[24] These rapids were caused by significant uplifting of portions of the riverbed. The resulting constriction caused significant flooding of surrounding areas, and is probably the source of the tale that the river flowed backwards for a while during the earthquake.[25] The new channel was eroded through the rapids within a few days.

The most dramatic evidence of subsidence was the creation of Reelfoot Lake in northwest Tennessee east of New Madrid.[26] Today the lake is eighteen miles long and up to five miles wide. Its depth varies from five to twenty-five feet.[27]

Liquefaction of the ground, both above and below the surface, produced many effects. Certainly, it contributed to the collapse of river banks and to localized subsidence; but the most significant effect was the eruption of "sand blows" (mud, water, sand, and stones thrown several yards into the air). It is estimated that 4,000 square miles were flooded at some time during the winter of 1811-1812 with as much as 3 feet of sand and water.[28] There is evidence that some of these spouts measured sixty feet in circumference.[29] Massive sand dikes were left behind by these erupted materials.[30]

Experienced river travelers recorded permanent changes to the navigable waterways throughout the region. Old islands had disappeared and new ones formed; river banks were reshaped; and new channels were created.[31]

More than 160,000 acres of timberland were destroyed by the combination of flooding, collapsing river banks, and local subsidence due to liquefaction.[32]

Fissuring, or open cracks in the ground surface, was prevalent up to hundreds of miles away from the epicenters. Larger fissures measured as much as twenty feet deep.[33]

Though settlement was sparse in the region at the time of the great earthquakes, destruction of man-made structures in the lands immediately surrounding the epicenters was total.[34] At locations further removed, eyewitness accounts describe lateral ground movement of twelve inches during the earthquakes, throwing houses and other structures off their foundations and causing the collapse of all masonry works, such as chimneys.[35]

Despite the severity of the earthquakes, deaths and other casualties were light. The total casualties can never really be accounted, especially among the native population that was in the area. Deaths on land were not extensive, and most of these were due to drowning in flood waters.[36] By this time, the Mississippi River system was the major trade route west of the Appalachian

Mountains, and consequentially, far more casualties occurred on the river than on land.[37]

For those European settlers living in the region at the time, the damage to their homes and livelihood was so severe that many fled the area.[38] It was twenty years before the population of the area around the NMSZ regained its pre-1811 level.[39] There was also a major exodus of the Delaware and Shawnee Indian peoples who had lived in the region.[40]

In addition to Indian lore which indicates that there were other great earthquakes in the NMSZ, there is substantial evidence of such prehistoric earthquakes. Researchers recently discovered that another great earthquake occurred in the southeastern Missouri area sometime between 1400 and 1670.[41] Prehistoric sand dikes and fissures in the region have been found which are bigger than those which were created during the 1811-12 earthquakes.[42]

There have been two major earthquakes in the NMSZ since the great earthquakes in the winter of 1811-12. The epicenters of these were in eastern Arkansas, west of Memphis, Tennessee (1843) and in southeast Missouri, west of Paducah, Kentucky (1895).[43] With improved scientific knowledge and modern detection instrumentation and equipment, it is now known that the NMSZ is presently active, producing hundreds of small earthquakes annually, though most are too small to be detected naturally.[44]

Likelihood of recurrence of a major New Madrid earthquake

Given the history of the NMSZ, the question that arises is not whether another great earthquake is likely to occur there, but when the next one might be anticipated.

There is some comfort to be found in seismic probability studies which suggest that a recurrence of multiple great earthquakes of 1811-1812 is 450 to 1000 years.[45] However, even a single great earthquake could have devastating effects. Extrapolation of earthquake statistics indicates that, over that same one thousand year period, the NMSZ could experience five great earthquakes (Richter magnitude 8) and fourteen major earthquakes (Richter magnitude 6 to 7).[46]

Recent earthquake research has theorized that current strain in the NMSZ could produce a major earthquake with a Richter magnitude of 7.6 if it were all to be released at once.[47] It has also been determined that potentially active faults are even closer to the cities of St. Louis and Memphis than previously thought.[48]

The results of these studies strongly indicate that damaging earthquakes are likely to occur within the lifetimes of people and structures in existence today.[49]

Assessment of damage expected of a major New Madrid earthquake

Using the near term likelihood of a major earthquake of Richter magnitude 7.6, the Federal Emergency Management Agency (FEMA) predicts damages, disruption, casualties, and injuries on a scale never experienced from a natural hazard in the history of the nation. The long term relief and recovery efforts would place a significant, prolonged burden upon the regional and national economy.[50]

Severe damage would occur in any area in which the Modified Mercalli Intensity rating is VII or greater. Figure 1 shows the extent of this area, covering approximately 250,000 square miles.[51] The Modified Mercalli Intensity Scale, reproduced in Table I, gives a description of the types of damage that could be expected at each level of intensity.

Casualty and injury figures would be affected by the time of day of an earthquake. If an earthquake occurred outside normal working hours, much of the population could be expected to be found in relative safe, flexible wood frame residential structures. Deaths would be expected to occur at a rate of 30 per 100,000 population.[52] If an earthquake occurred instead during a typical work and school day, when a majority of the population moves into buildings which are much more vulnerable to severe structural damage or collapse, the figures would be significantly higher with approximately one-quarter of the casualties and injuries being among school children. The

estimated number of deaths during a daytime event would be 288 per 100,000 population.[53] Estimated injury rates would be approximately four times the death rates in both cases.[54]

Adequate medical services for the disaster area would require extensive outside assistance. Not only would the existing health care facilities be insufficient to manage the level of requirements, but many of those facilities would be lost due to severely damaged or collapsed hospital structures.[55]

Transportation systems would be seriously damaged. Highway access around major metropolitan areas, such as Memphis and St. Louis, would be severely limited with bridge collapses cutting or blocking most major arteries in many locations. Railroad systems, which are designed and constructed to much more demanding specifications than highways, would experience even greater damage. FEMA estimates that as much as 75 percent of the rail systems in the Memphis area would not survive an major earthquake.[56] Almost all bridge spans across the Mississippi River would be closed, if not collapsed, due to structural damage.

It is more difficult to estimate the probable impact on river traffic, but it would certainly be significant. River ports are expected to be extensively disrupted. Previously navigable river channels may become clogged with debris from massive landslides or actually may be obstructed by uplifted strata of the river bed.[57]

Partial or limited availability of major airport facilities is expected following a major earthquake. Navigation and landing aids may be lost or interrupted temporarily due to loss of electricity. Runways will likely sustain certain kinds of damage but still have enough useable length to allow operations of military aircraft capable of short take-off and landings.[58]

Most major metropolitan areas within the high intensity zones will experience serious impairment or loss of the four main utility systems - electricity, water supply , natural gas, and waste water collection and treatment. The most critical of these, electrical supply, is unfortunately the most vulnerable and will be almost universally unavailable throughout a large area of the central United States. Depending upon the locale, the extent of local damage and disruption, and the criticality of need, these outages will range from a period of days to months.[59]

Numerous other facilities and institutions critical to the life and maintenance of larger metropolitan areas will be similarly adversely affected. These include police and fire stations, schools, communications facilities, radio and television broadcast facilities, mail distribution, ambulance services, blood banks, finance institutions, and churches.[60]

As in the major earthquakes of 1811-12, extensive flooding is expected, especially in low lying areas near major waterways. The Mississippi River may likely changed its primary channel in some locations, leaving behind large bayous and inundating

hundreds of acres of adjacent land. In the event of a major earthquake, the modern day flood control structures, especially the earthen dikes and levees, would not be effective in preventing flooding. In many cases these structures would fail when their subgrades liquefy. The most vulnerable areas, the low lying regions near major waterways, are mostly undeveloped and uninhabited, indicating relatively few casualties would be expected. However, any general occurrence of flooding would increase the number of displaced persons and add to the necessary relief efforts.[61]

Environmental damage would be significant. The Mississippi River flood plain contains many large storage facilities with vast quantities of fuels, fertilizers, and chemicals. FEMA has identified over 7,000 hazardous chemical storage sites in the region.[62] Most regional municipal waste water treatment facilities are also located in these flood plains. Damage to these structures, along with land fills and pipelines, will cause widespread contamination of rivers, groundwater, and water distribution systems.[63]

Based upon the National Inventory of Dams data, over 7,000 dams are located in the NMSZ. Of these, approximately 900 are considered "high risk" for possible failure during a major earthquake. Significant downstream flooding at these dams should be expected.[64]

The central Mississippi Valley is one of the most productive agricultural areas of the United States. Not only would farming be disrupted by earthquake damage, but the extensive canal system that drains water from low lying arable lands could be damaged by liquefaction and landslides and by uplift of land surface. Large areas could be inundated by water or covered by liquefied sand vented to the ground surface. Electric outages would affect pumping and other equipment systems.[65]

While giant fires or conflagrations are unlikely due to the nature of modern metropolitan structures, widespread individual and small scale structural fires are likely due to the earthquake damage. Most fires will result from damage to natural gas and electric utilities or to flammable liquid spills. These fires will have a much greater than expected impact, however, as most local fire fighting and suppression capabilities will have been lost in the earthquake.[66]

Many individuals will find themselves displaced from their homes due to structural damage, loss of adequate utilities and services, flooding, and other disaster related causes. While some of these people may find alternative living arrangements in surviving, relatively undamaged structures, FEMA estimates that the number of displaced persons will approach one million.[67] Providing adequate shelter and services for these may not be reasonably possible for several weeks following the earthquake.

As a result, hundreds of thousands of displaced persons may be expected to migrate away from the central United States region.

One quarter of the energy consumed annually in the United States moves north and northeast from Texas, Oklahoma, and Louisiana to support the densely populated northeast and north central United States. Most of the energy moves by pipeline in the form of crude oil, petroleum products, and natural gas. Nearly all the crude oil production from this region is transported through these pipelines to refineries.[68]

At risk, also, is the interstate natural gas distribution system which passes through the NMSZ on its way from the production fields on the Gulf coast to the major metropolitan areas further north. The major terminal points of this system include New York, Philadelphia, Pittsburgh, Boston, Buffalo, Detroit, and Chicago. Even though the system consists of multiple parallel underground pipeline, a major earthquake would interrupt transmission through the region. Depending upon the time of year, such interruption of service, even temporary, could have a devastating negative impact upon large regions of the country beyond the immediate NMSZ.[69]

Almost too overwhelming to imagine is the financial and economic burden that a major earthquake will be, not only upon the NMSZ, but the entire nation. FEMA estimates that the cost of restoring damage or replacing losses will approach $50 billion.[70] Yet that only accounts for a portion of the cost. The loss of

business and commerce throughout the region will have a serious negative impact upon the nation's economy in terms of loss of gross national product.

Following a major earthquake, the recovery will be long and difficult. The surviving resources within the affected region will be unable to adequately provide the necessary emergency response. This means that very large scale outside support and assistance of all kinds will be the primary means to reduce further loss of life, suffering, and disruption to regional lifelines.[71]

Federal planning for response and recovery

FEMA is sponsoring an on-going effort through its Central United States Earthquake Preparedness Project (CUSEPP) to reduce the hazards associated with a major New Madrid earthquake. The project aims to accomplish this through determination of the potential consequences of a major earthquake, an increase of the awareness of those consequences among public officials and the private sector, the development of response plans for coping with them, and the implementation of actions for reducing them.[72]

State and local governments are responsible for measures to mitigate earthquake effects. These measures include such actions as passing and enforcing earthquake resistant design standards and upgrading existing public buildings and infrastructure. In view of how a major earthquake will affect local capabilities,

however, much of the effort to prepare for response and recovery operations falls to the state and federal governments. This is the area which will directly impact various Department of Defense agencies.

Once a major earthquake occurs in the NMSZ, local governments will be unable to respond adequately. There will be immediate requirement for emergency recovery operations, replacement of basic life support means, and maintenance of law and order within the affected region. In order to assist local and state authorities in these functions, the state governors will activate those National Guard units which are capable of responding. In recent years, several regional states have signed cooperative agreements to allow their National Guard units to cross state boundaries to provide emergency assistance during a natural disaster.[73]

Given the wide area that would be affected and the operational tempo of National Guard units in support of federal missions today, it is not unreasonable to expect that some state Guard units might not be immediately available. Whether the federal government would allow these units to return to the control of the state governors is a question which probably cannot be answered in advance. That would obviously be a matter of consideration based upon several factors, such as the location of current deployment, the sensitivity of the federal mission,

the degree of need in the state, and the availability of other federal assets to replace the requirement for Guard units.[74]

It is expected that the President would soon declare the affected region a federal disaster area, thus triggering the execution of the Federal Response Plan (FRP) under the direction of FEMA. The FRP is an umbrella interagency agreement developed to coordinate support to state and local governments. It covers twelve Emergency Support Functions (ESF) which will be performed by various federal agencies. dod has a standing mission within FRP for ESF#3, Public Works and Engineering. The U.S. Army Corps of Engineers has been designated as the lead dod agency for planning and execution of this function.[75] The planning effort is still on-going, but it will include details for providing the following areas of support to state and local governments: emergency clearance and removal of debris; temporary construction of access routes; emergency restoration of critical public facilities; demolition and/or stabilization of damaged structures; emergency contracting for humanitarian support; technical assistance; damage survey reports; emergency power; and temporary housing.[76]

FEMA may also call upon dod agencies to support the execution of the remaining eleven ESFs of the FRP. How this will be managed by dod is still an evolving process, but the basic procedures have been laid out. Within dod, the Secretary of the Army is designated as the Executive Agent for Military Support to

Civil Authorities. The Secretary will exercise operational control over all dod components, including services and defense agencies. The Army's Directorate of Military Support (DOMS) performs the planning and coordination of this support on behalf of the Secretary.[77]

In the case of a New Madrid earthquake, once DOMS received a tasking from FEMA to provide support under the FRP, the requirement would be passed to the United States Atlantic Command (ACOM). One of the expected responses from ACOM would be to task the United States Forces Command (FORSCOM) to establish an adequate number of field offices and to staff each one with a Defense Coordinating Officer (DCO). The role of the DCO is to validate all requests for dod assistance which are then passed to the appropriate Army headquarters or to the Joint Task Force, is constituted. Given the expected level of support that will be required in the aftermath of a major earthquake, ACOM will certainly establish a JTF to command and control all dod elements participating in the response and recovery effort, with the exception of the Corps of Engineers which will respond directly to FEMA.[78]

The location of the NMSZ will create a coordination nightmare for most federal agencies, because the zone lies on the boundary of multiple subordinate elements of most federal agencies. Even FEMA will have to struggle with this as four of its subordinate regions overlap the NMSZ. The Corps of Engineers

will have to manage a similar coordination effort among its many Civil Works Districts that will be affected. Though the Mississippi River divides responsibility for the continental United States between the First Army and the Fifth Army, the formation of a JTF will spare dod any major coordinating challenges based upon geographical areas of responsibility.

Summary and Conclusions

The history of seismic activity in the New Madrid Seismic Zone, and the findings of recent research in this area have made it plain that there is a high probability of a major earthquake occurring in the American heartland in the near term future. It is impossible to control those forces of nature which will trigger such an event, and it is almost impossible to predict when or exactly where it will occur.

Within the Department of Defense, we must continue to plan and train for the types of missions that massive disaster response and recovery will produce. In a time of limited resources and overextended commitments, it is difficult to carve out the time, money, and material resources to prepare for a mission that may not occur for several years. Yet, failure to prepare properly could mean much more suffering and casualties than necessary.

It is also worthwhile to contemplate what some of the second or third order effects of a massive natural disaster might be for

the military. If the nation's economy were to suffer significantly, or if the disaster required a huge outlay of unprogrammed expenses for recovery, then federal defense expenditures might be adversely affected. Also, such an event might provide a window of opportunity to our adversaries abroad, especially those rogue nations and elements which are not able to directly confront us with anything beyond asymmetric means.

Some military facilities are located in the high risk areas, such as Millington Naval Air Station, near Memphis, Tennessee, and Scott Air Force Base, in St. Louis, Missouri. Also, several defense-related contractors and suppliers operate out of facilities located here in the central United States.

The ramifications of a major New Madrid earthquake will affect all sectors of the nation and our society. Thus, it is imperative that everything possible be done to prepare for such an event, to be ready to respond and to assist in recovery. This may, indeed, be one of the most critical roles the Department of Defense will ever have to perform in support of the nation.

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Table I - MODIFIED MERCALLI INTENSITY SCALE[79]

Intensity	Description of observed damage types
I.	Not felt except by a few under especially favorable conditions.
II.	Felt only by persons at rest in places such as upper floors of buildings. Delicately suspended objects swing.
III.	Felt by many persons in places such as upper floors of buildings but of a degree that most persons do not recognize it as an earthquake. Standing automobiles may rock slightly as if from vibration caused by a passing truck. Duration may be measured.
IV.	In daytime, felt by many indoors but by only a few outdoors. Dishes, windows, doors disturbed, and walls creak. Sensation like a heavy truck striking a building. Standing automobiles rock considerably.
V.	Felt by all, many awakened. Some dishes and window glasses broken, wall plaster may crack. Unstable objects overturned. Disturbance of telephone poles, trees, and other tall objects sometimes noticed. Pendulum clocks stopped.
VI.	People are frightened and run outdoors. Heavy furniture may be moved; some instances of fallen plaster and toppling of chimneys. Slight damage.
VII.	Everybody runs outdoors. Damage negligible in buildings of good design and construction, slight to moderate in ordinary structures, and considerable in poorly built or badly designed structures. Chimney broken. Felt in moving automobiles.
VIII.	Some damage even in buildings of good design and construction. Considerable damage in ordinary buildings, with some collapsing. Great damage in poorly constructed buildings. Panel walls thrown out of frame structures. Falling of houses and factory chimneys, columns, monuments, and walls. Heavy furniture overturned. Changes in well water. Hinders driving of automobiles.

IX. Damage considerable in buildings of good design and construction. Structures thrown out of alignment with foundations. Ground cracked conspicuously. Underground pipes damaged.

X. Wooden houses of good design and construction collapse. Most masonry and frame structures destroyed together with foundations. Ground cracked causing damage. Rails bent. Slopes and embankments slide. Water surface rises.

XI. Almost all masonry structures collapse. Bridges destroyed. Fissures over entire surface of ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent prominently.

XII. Damage total. Waves seen transmitted at ground surface. Topography changed. Objects thrown into the air.

ENDNOTES

[1] Robert M. Hamilton and Arch C. Johnston, eds., Tecumseh's Prophesy: Preparing for the Next New Madrid Earthquake, A Plan for an Intensified Study of the New Madrid Seismic Zone, U.S. Geological Survey Circular 1066 (Washington, D.C.: U.S. Government Printing Office, 1990), 1.

[2] Hamilton, 7.

[3] Federal Emergency Management Agency, An Assessment of Damage and Casualties for Six Cities in the Central United States Resulting from Earthquakes in the New Madrid Seismic Zone, Report of the Central United States Earthquake Preparedness Project (CUSEPP) (Washington, D.C.: Federal Emergency Management Agency, October 1985), 1-4.

[4] This refers to the work of Myron L. Fuller which was reported in USGS Bulletin 12, The New Madrid Earthquake, 1912.

[5] Kaye M. Shedlock and Arch C. Johnston, Introduction - Investigations of the New Madrid Seismic Zone, U.S. Geological Survey Professional Paper 1538-A (Washington, D.C.: U.S. Government Printing Office, 1994), 2.

[6] W. L. Ellis, Summary and Discussion of Crustal Stress Data in the Region of the New Madrid Seismic Zone, U.S. Geological Survey Professional Paper 1538-B (Washington, D.C.: U.S. Government Printing Office, 1994), 1.

[7] The theory of plate tectonics is a subject of widespread academic instruction and any good college level geology textbook will provide adequate discussion of the subject. In preparation of this paper, I referred to M. J. Selby, "Global Tectonics," in Earth's Changing Surface, An Introduction to Geomorphology (New York: Oxford University Press, 1990), 38-61.

[8] Shedlock, 1.

[9] Ibid.

[10] FEMA, 1-13 thru 1-14.

[11] Ibid., 1-6.

[12] Shedlock, 5.

[13] FEMA, iii.

[14] Ibid., 2-17.

[15] Roy Van Arsdale, "Hazard in the Heartland: The New Madrid Seismic Zone," Geotimes, May 1997, 16.

[16] FEMA, ii.

[17] Hamilton, 11.

[18] James Penick, Jr., The New Madrid Earthquakes of 1811-1812 (Columbia, MO: University of Missouri Press, 1976), 6.

[19] Van Arsdale, 16.

[20] Hamilton, 8.

[21] Penick, 2-5.

[22] Hamilton, 12.

[23] Penick, 46-49.

[24] Ibid., 74.

[25] Norma Hayes Bagnall, On Shaky Ground, the New Madrid Earthquakes of 1811-1812 (Columbia, MO: University of Missouri Press, 1996), 42.

[26] Penick, 76.

[27] Ibid., 95.

[28] Hamilton, 12.

[29] Penick, 101.

[30] Ibid., 96.

[31] Ibid., 57-59.

[32] Hamilton, 12.

[33] Penick, 99-100.

[34] Ibid., 113.

[35] Ibid., 32-40.

[36] Bagnall, 27.

[37] Penick, 57.

[38] Van Arsdale, 18.

[39] Penick, 51.

[40] Bagnall, 55.

[41] "Groundbreaking News," Geotimes, January 1998, 7-8.

[42] Van Arsdale, 18.

[43] FEMA, 1-2.

[44] Ibid., 1-6.

[45] Van Arsdale, 18.

[46] Arch C. Johnston and S. J. Nava, "Recurrence Rates and Probability Estimates for the New Madrid Seismic Zone," Journal of Geophysical Research 90, no. B8 (1985): 6745.

[47] FEMA, ii.

[48] Van Arsdale, 18.

[49] FEMA, 1-6.

[50] Ibid., ii.

[51] Hamilton, 12.

[52] FEMA, 3-33.

[53] Ibid.

[54] Ibid., iv.

[55] Ibid., v.

[56] Ibid., vi.

[57] Ibid., vii.

[58] Ibid., viii.

[59] Ibid., viii-ix.

[60] Ibid., ix.

[61] Ibid., x.

[62] Risk Management Solutions, Inc., Preliminary Estimates of Four New Madrid Earthquake Events for Use by FEMA's CAT97 Exercise (Menlo, CA: Risk Management Solutions, Inc., 26 August 1996), 31.

[63] Hamilton, 15.

[64] Risk Management, 33.

[65] Hamilton, 15.

[66] FEMA, x.

[67] Ibid., x-xi.

[68] Russell L. Wheeler, Susan Rhea, and Arthur C. Tarr, eds., Elements of Infrastructure and Seismic Hazard in the Central United States, U.S. Geological Survey Professional Paper 1538-M (Washington, D.C.: U.S. Government Printing Office, 1994), 9-11.

[69] FEMA, 3-27.

[70] Ibid., xi.

[71] Ibid., xii.

[72] Ibid., I.

[73] Richard Roman, Deputy Director, Central United States Earthquake Consortium (CUSEC), telephone interview by author, 13 January 1998.

[74] Many of the legal questions related to this were addressed by the United States Supreme Court in Perpich v. Department of Defense, Case No. 89-542, June 1990. In finding for the

Department of Defense, the Court determined that the federal government had the authority to order state National Guard units to training outside their state boundaries, but it also affirmed the primary control of state governors over their National Guard units in times of emergency.

[75] Department of the Army, USACE Response Operations in the United States, Engineer Pamphlet (Draft) 500-1-4 (Washington, D.C.: U.S. Department of the Army, 30 June 1997), 1.

[76] Michael J. Shama, Chief, National and Military Plans and Policy Section, HQ U.S Army Corps of Engineers, telephone interview by author, 13 January 1998.

[77] David L. Grange and Rodney L. Johnson, "Forgotten Mission: Military Support to the Nation," Joint Forces Quarterly (Spring 1997): 109.

[78] Philip Magliore, Chief, Domestic Plans and Policy, J-5, United States Atlantic Command, telephone interview by author, 12 February 1998.

[79] Hamilton, 7.

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